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STUDIES OF THE NEBULAE

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This modest title gives small indication of the amount and variety of the contents of this splendid volume. An outline has already been published by Professor Campbell in the February number of this Journal. The volume is divided into six parts, each of which is worthy of an independent review.

Part I. *Descriptions of 762 Nebulae and Clusters photographed with the Crossley Reflector*, by Heber D. Curtis. The illustrations in this Part, and indeed thruout the volume, add greatly to the value as well as the appearance of the publication.

The study of the nebulae at the Lick Observatory was begun by Keeler, whose early work is so well known thru the Memorial Volume, No. VIII, of the Observatory Publications. The present list of nebulae and clusters includes early as well as late objects obtained with the Crossley Reflector. A careful description of these 762 objects is given, which adds much to our knowledge concerning them. One of the most interesting developments of this study is the information gained concerning the number of the spiral nebulae. On the photographs containing the objects especially sought were found a great number of uncatalogued nebulae, which in many cases were plainly spiral, and, in practically all cases, presumably so. The somewhat arbitrary distribution of the 762 objects might have been expected to give misleading conclusions as to the number of faint nebulae in the whole sky. It has long been known that the small, *white* nebulae avoid the Milky Way, and, as shown so clearly by Wolf in 1902, are massed in great numbers near the north galactic pole. They are much less numerous at the south galactic pole. To the Lick observers is due chiefly the surprising discovery that nearly all these faint objects are spiral nebulae. These spirals seem to bear a definite relation, that of avoidance, to the Milky Way. Keeler estimated the number of such nebulae at 120,000, Perrine at 500,000 and other observers have given different estimates. Dr. Curtis, from a careful consideration of the photographs obtained by himself and his predecessors, and allowing for the unsystematic

distribution of the regions examined, places the number which can be reached with the Crossley Reflector at 700,000, possibly 1,000,000. Formerly such figures would have startled us, but there is now no reason to doubt the essential truth of Dr. Curtis' estimate. Incidentally, it is not without interest that among the multitude of these faint nebulae, few, if any, additions have been made to the number of the globular clusters. Several years ago attention was called to the apparent finality of our list of globular clusters. The conclusions of Dr. Curtis appear to confirm the essential accuracy of this statement.

Part II. *A Study of the Occulting Matter in the Spiral Nebulae.* In this Part Dr. Curtis continues his studies of the nebulae. Many details are given in the text, but, to be convinced of the truth of the author's claims, one hardly needs more than to look at the illustrations. A comparison is made between the dark streaks on the spiral nebulae and the dark patches in different parts of the Milky Way, formerly regarded as "holes." In some cases the dark lanes of the spirals have the appearance of partially open spaces between the whorls. In many instances, however, straight absorption bands are seen lying along the axes of the nebulae, apparently viewed on edge. The conclusion seems inevitable that such bands consist of occulting matter intimately associated with the nebulae themselves. Various theories are discussed by the author, but the view that such dark areas, either in the nebulae or in the Milky Way, are vacant spaces is no longer tenable.

Part III. *The Planetary Nebulae.* This Part, also by Dr. Curtis, is an elaborate study of the form and structure of the planetaries. All his investigations are valuable not only for their own worth as scientific studies, but also for the light they throw on the researches which follow relating to the radial velocities and spectra of the gaseous nebulae. Curtis divides the nebulae into three classes: spirals, planetary and diffuse. That the spiral nebulae deserve a class by themselves will not be questioned, this by virtue of their structure, motion and spectrum. The distinction between the planetary and diffuse nebulae seems not so well established. The appearance is distinct, but the character as shown by the spectrum is similar. The number of the planetaries is small, amounting probably to only 150 in the whole sky. That this limit is genuine and not apparent was tested by the author with a slitless spectroscope on 79 small nebulae. Only one of these proved to have a

planetary spectrum, all the others having a continuous spectrum. The same fact is shown in the results of the *Henry Draper Catalogue*, which increases the number of classified spectra from 9000 to more than 200,000, with the addition of only one planetary spectrum.

In general the planetary nebulae show a decided preference for the galactic circle, and even the apparent exceptions to this law may be explained as comparatively near objects, really members of the galactic system, altho projected upon other parts of the sky. Such objects are in general larger and hence presumably nearer than the others. The same may be true of the diffuse nebulae. It is of considerable interest that at least four classes of celestial objects, globular clusters, planetaries, diffuse nebulae and Wolf-Rayet stars, are few in number and appear to have a definite limit already approximately attained. All except the globular clusters are found only in the Galactic system or in the Magellanic Clouds. Dr. Curtis has photographed all the planetaries within reach of the Crossley Reflector, 78 in number, using exposures from a few seconds to two hours. Several exposures of varying length were necessary to bring out the different characteristics. When the objects were small and difficult, drawings were made, which incorporate more details than a single photograph could do. The diameters of the planetaries vary from a few seconds to several minutes of arc. One of the most usual and characteristic features is a central star placed within a small and well-defined round or elliptical nebula. The central star, or nucleus, is seldom wanting. The various forms in which these nebulae appear are illustrated with elaborate care. The descriptions and illustrations are followed by a study of the theory of their construction. For the most part they are explained as gaseous spheres, or as ring or ellipsoidal shells. Curtis discusses the place of planetary nebulae in the scheme of stellar evolution. This will be referred to later.

Part IV. *The Spectroscopic Velocities of the Bright-Line Nebulae*, by William W. Campbell and Joseph H. Moore. This paper is the longest in the volume. It would be difficult to exaggerate its importance. Following a résumé of previous investigations along the same line, and a discussion of the instrumental means employed, Director Campbell and Dr. Moore give an elaborate description of their observations and results. These not only deal with the motion of the nebula as a whole, but with differential motion in the nebula

itself. The great accuracy of the determinations is indicated by the probable errors. These, for a single observation of the brighter nebulae, amount to only 0.5 km. For fainter objects, when exposures of ten to twenty hours were necessary, and for results obtained in Chile with a less powerful equipment, the probable error is naturally somewhat greater. Such errors are negligible in comparison with the great velocities frequently found. The great nebula in *Orion* was studied in special detail. While its integrated velocity referred to the stars is near zero, the differential motions of closely related areas are conspicuous, amounting to as much as 10 km./sec. Relative motion within the mass of various other nebulae is also indicated by the bent and twisted forms of some of the spectral lines. That they are not rotating as solid bodies is clearly shown by the form of these lines.

The radial velocities of 125 gaseous nebulae were measured at Mount Hamilton and Santiago. From the only bright-line nebula in the Small Magellanic Cloud, a radial velocity of +157 km./sec. was found, when corrected for the solar motion, and this is probably that of the Cloud. From seventeen determinations in the Great Magellanic Cloud a mean radial velocity of +261 km./sec. resulted. These velocities indicate independent systems. The authors give the results of a study of the solar motion as deduced from the planetary nebulae. These results, as might be expected, vary enormously according to the number and grouping of the nebulae employed.

The rotational velocities of a few of the nebulae permitted, with certain assumptions, conclusions regarding their masses. Of three cases given, the masses are 162, 3.7 and 18.8 times that of the Sun. The planetary nebulae in which rotational effects were observed appear to be at least several times as massive as the Sun, but the fainter and apparently smaller planetaries are probably less massive in some cases than the solar system.

The general results are summarized at the end, but are too long for quotation. They are full of interest. In addition to the eighteen bright-line nebulae in the Magellanic Clouds, six of the observed nebulae had velocities greater than +115 km./sec. The average velocity of the thirty-six smaller nebulae, with reference to the stellar system, is 28 km./sec., and that of the other sixty-five objects 31 km./sec. These velocities are about five times that of the Class B stars, a fact having large importance in the theory of

stellar evolution. The mean velocity of the five irregular nebulae with reference to the stars is 11 km./sec. The evidence for a Kapteyn preferential motion of these nebulae is slight.

Part V. *The Radial Velocity of the Greater Magellanic Cloud*, by Ralph E. Wilson. This paper gives in detail the determination of the velocity already referred to in Part IV. Some interesting comments are presented on the structure of the Cloud and its resemblance to the Milky Way. The mean radial velocity for the seventeen observed nebulae is doubtless that of the Cloud as a whole, but an attempt was made to verify this by a determination of the velocities of the stars of Class O which are closely associated with it. Unfortunately, the result was inconclusive on account of the faintness of the spectrograms obtained. Previous determinations of the velocities of the bright stars in the region gave a mean velocity of + 6 km./sec., which would be more than accounted for by the recession of the solar system. These bright stars, therefore, are not members of the Cloud but merely projected upon it. Dr. Wilson finds that if 30 *Doradus* is regarded as the nucleus of the Cloud, the northern regions appear to be receding with velocities higher than those near the center, suggesting a rotation about an axis approximately at right angles to the line of sight. The evidence, however, is slight. The author suggests that the Greater Cloud may be a typical spiral nebula, nearer to us than the other spirals.

Part VI. *The Wave-Lengths of the Nebular Lines and General Observations of the Spectra of the Gaseous Nebulae* by William H. Wright. The primary object of this investigation was not discovery but increased accuracy in the determination of the wave-lengths of the known nebular lines. The research was divided into three divisions: 1. The measurements of wave-lengths and the intensities of nebular lines. 2. The study of nebular nuclei. 3. The distribution of nebular radiations thruout the nebulae. The observations are given in detail and are beautifully illustrated by photographs taken with both the slit and the slitless spectrograph. The results depend chiefly upon the measurements of the spectra of nine bright nebulae. Professor Wright has used two scales to represent the relative intensities of the lines, designated Ig and Iq, according as the observation was made with a glass or a quartz prism. Of special interest is Chapter III, in which the relationship between the planetary nebulae and the stars of Class O (Wolf-Rayet

stars) is discussed. The distribution of these two groups is similar, as was pointed out long ago by Pickering. A little later Keeler announced his conviction that the nuclei of the planetaries are closely related to the Wolf-Rayet stars. As regards the Harvard classification of these nebulae and stars as Classes P and O, it must be remembered that the work at Harvard has all been done on plates made with the objective prism, and that there is always difficulty in distinguishing between the spectrum of the nucleus and that of the nebulous envelope. Professor Pickering's arrangement of both classes in one group, which he called Fifth Type Stars, appears to be justified in the light of recent knowledge. Wright states that out of thirty nebular nuclei about one-half are Class O stars. The relation, therefore, between the planetary nebulae and Class O stars seems to be well established. Wright suggests the following grouping:

1. Nebulae without nuclei.
2. Nebulae with nuclei. The nuclei are in all instances of very high temperature, and in half the cases show Class O bands.
3. Class O stars, with no (observed) nebulous surroundings. Temperature high.

The author states that the invariable characteristic of the nucleus spectrum is a remarkable extension into the ultra-violet, and would make this fact the dominating peculiarity of the group. The energy curve which this spectrum gives, if interpreted as a heat phenomenon, probably indicates the highest temperature of any stars known. The nebular envelope may be of a much lower temperature. Wright also discusses the relationship of the Novae, whose spectrum is found to correspond rigorously with that of the nebulae.

We have thus an extremely intimate relation between the gaseous nebulae (Class P), the Wolf-Rayet stars (Class O) and the Novae. What place in stellar evolution do they occupy? This question is considered in various places in the volume. Notwithstanding the immense accumulation of data, apparently no final answer can be given. That there is a relation between the spectra of Class O, especially the later divisions, Classes Od and Oe, and Class B was shown by Miss Cannon in 1901, in *H. A.* **28**, 141, when the designation Oe5 was given to spectra which are intermediate. Nevertheless, it would be unsafe to infer that, in general, stellar evolution begins with, or passes thru, Classes P and O to reach Class B and the other classes in the descending series. It has been suggested

that the stars of Classes P and O may be the special, rather than the usual, development of giant stars and that the vast majority never attain such high temperatures. The great difference in mean velocity appears to form a barrier between the planetary nebulae and stars of Class B; but, where individual results vary so widely, it may be possible to overestimate the importance of mean results.

In conclusion, it is a pleasure to state that the present volume of the Lick Observatory PUBLICATIONS is a model of its kind. It is filled with exact facts, the results of wisely planned and skilfully executed investigations, together with deductions and theories which are at once moderate and convincing. It goes far toward giving that broad foundation of scientific fact without which any superstructure however glittering is not apt to endure.

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